AN EXPERIMENTAL INVESTIGATION OF SINGLE ALUMINUM "METEOR BUMPERS"

By Don Humes, R. N. Hopko, and William H. Kinard

NASA Langley Research Center
Langley Air Force Base, Va.

For presentation at the Fifth Hypervelocity Impact Symposium

Denver, Colorado
October 30-November 1, 1961

AN EXPERIMENTAL INVESTIGATION OF SINGLE ALUMINUM "METEOR BUMPERS"

By Don Humes, R. N. Hopko, and William H. Kinard

For presentation at the Fifth Hypervelocity Impact Symposium

INTRODUCTION

Man and machine are now traveling in a new environment - space. Meteoroids are part of this environment and thus pose a potential hazard to the space traveler. Considerable research effort is being directed to define this hazard. If it is discovered that meteoroids pose a serious hazard to space vehicles, means of reducing the hazard must be found. Several fabrication techniques to reduce the damage from meteoroid impacts are presently being studied. This report describes an investigation of one fabrication technique which utilizes a "Meteor Bumper", first proposed by Fred Whipple as a means of reducing impact damage. Figure 1 illustrates the meteor bumper which is simply a thin shield placed a short distance in front of the main structural wall. It is envisioned that meteoroids would be fragmented and/or vaporized upon impacting the bumper and the resulting debris dispersed over a large area of the main wall.

Scope of the Present Investigation

In this investigation, the bumper shield thickness and the spacing between the bumper shield and the main structural wall have been varied. The bumper shields were 2024-T3 aluminum alloy and varied in thickness from 0.016 to 4.0 projectile diameters. The main walls were all 2024-T4 aluminum alloy.

In order to efficiently study the effectiveness of the various bumper shields, the main structural walls were all thick enough to be considered quasi-infinite.

The spacing between the bumper shield and the main walls varied from 0 to 96 projectile diameters. The projectiles used in obtaining penetration data were 0.0625-inch-diameter copper spheres and were saboted during firings from both powder guns and light gas guns. Several 0.220-inch-diameter aluminum spheres were fired to obtain photographic data. The bumper targets impacted by projectiles fired from the light gas guns were contained in an evacuated test chamber while impacted. The targets impacted by projectiles fired from the powder guns were mounted in an open range. Instrumentation was employed to measure the velocity of the projectiles and to establish that the projectiles were launched undamaged and separated from the sabots before impacting the targets.

Discussion of the Results

Effect of impact velocity.- The effect of projectiles impacting bumper shields at various impact velocities is shown in figure 2. This figure shows photographs of 0.22-inch-diameter aluminum spheres after penetrating 1/8-inch-thick aluminum bumpers at impact velocities of 2,700, 4,600, 7,300, and 13,400 feet per second. At the impact velocity of 2,780 ft/sec the projectile which probably is the leading large fragment is essentially intact suffering only a slight deformation. One plug punched from the bumper can be seen following the projectile and a small ring of metal is visible just being spalled away from the bumper. When the impact velocity was increased to 4,850 ft/sec the projectile appears to be fractured

in several large fragments which are remaining close together in a roughly small spherical pattern. Behind the projectile fragments can be seen a cone of bumper fragments. When the impact velocity was further increased to 7,250 ft/sec the projectile fragmented into smaller fragments which spread out such that they are indistinguishable from the fragments from the bumper. At the highest impact velocity of 13,400 ft/sec an expanding elliptical cloud of very small fragments was found.

The total measured penetration observed in a bumper protected wall combination at varying impact velocities is illustrated in figure 3. The total penetration which is the bumper thickness penetrated plus the penetration in the main target is plotted on the ordinate with the impact velocity plotted on the abscissa. Plotted for comparison purposes are the penetrations achieved at identical impact velocities in quasi-infinite targets with no bumper shields. The thickness of the bumper shields used were all one-half the diameter of the impacting projectiles.

It can be noted that the penetration into the unprotected quasi-infinite targets increased with increasing impact velocities for the entire velocity range observed. In the low velocity range, the penetration into the bumper protected targets also increased with increasing impact velocities up to a velocity of about 6,000 ft/sec. At this velocity the penetration appears to reach a maximum value and as the impact velocities are further increased the penetration decreases.

Examination of the data shown in figure 3 in the low velocity range shows that at these impact velocities the bumper shields were ineffective in reducing the penetration. In fact the projectiles penetrated deeper in the

bumper protected targets than in the unprotected targets. This greater penetration in the bumper targets was due to the fact that less projectile momentum or energy was required to penetrate the bumper shield than was required to penetrate an equal depth in the quasi-infinite targets. This fact has been shown in reference 1. In the low velocity range the copper projectiles were intact and essentially undeformed after penetrating the bumper shield as was the low velocity aluminum projectile shown in figure 2.

Penetration data of figure 3 at impact velocities above 9,000 ft/sec shows that the bumpers were effective in reducing the total penetration below that obtained in the unprotected targets. The copper projectiles were observed to begin fragmenting during the penetration of the bumpers at impact velocity above 9,000 ft/sec, almost twice the velocity required to begin fragmenting the larger aluminum projectiles illustrated in figure 2.

The fragmentation of the higher velocity projectiles as they penetrated the bumper and the dispersion of the fragments over a large area of the main target accounts for the ability of the bumper shield at the higher impact velocities to reduce the penetration.

In hypervelocity impacts the crater volumes are observed to be a function of the kinetic energy of the impacting projectiles. In a bumper target system the energy is spread over a large area of the main target due to the projectile fragmentation and the dispersion of the fragments and there is a tendency to produce a very large diameter shallow crater rather than the usual hemispherical craters observed in unshielded targets. If the distance between the bumper and the main target is sufficient, many small individual

craters are produced. The small crater having the deepest penetration will be that one produced by the fragment having the greatest energy.

The decrease in penetrations with increasing impact velocities shown in the high velocity range of figure 3 results from an increase in the degree of projectile fragmentation which occurred at higher and higher impact velocities.

The velocities of the particles resulting from the penetration of a bumper shield vary widely. The measured velocities of the fastest fragments observed always increased with increasing impact velocities as shown in figure 4. The increased rate of projectile fragmentation with increasing impact velocities shown in figure 2, however, overshadowed the effects of the increasing fragment velocities and caused the penetration to decrease.

If the fragment sizes and the fragment velocities continue to change at velocities above 16,000 ft/sec as they have in the 9,000- to 16,000-ft/sec range then it is possible that the penetration depths in bumper protected targets may decrease and approach being equal only to the bumper thickness. If this trend be correct then it appears that possibly the maximum impact penetration damage to a shield protected wall may result from particles impacting at rather low velocities.

Effect of bumper spacing.- The effects of the spacing between the bumper shield and the main wall are illustrated in figure 5. This figure is a plot of the total penetration as a function of shield standoff.

It can be seen that at impact velocities up to about 9,000 ft/sec the penetrations were not affected by standoff. In this velocity range as has been mentioned the projectiles remained intact after penetrating the bumper.

At impact velocities above 9,000 ft/sec in which cases the projectiles were fragmented by the bumper the penetrations were observed to decrease with increasing standoff up to a point beyond which additional increases in the standoff had no further effect. The decrease in the penetration observed as the standoff distance was increased up to about 40 times the projectile diameter occurred as the result of the greater dispersion of the fragments and consequently the reduced number of compound craters formed. The compound craters are those craters formed by two or more fragments impacting on or near the same location and consequently influencing the penetration depth of each other.

A typical dispersion patternof fragments is illustrated in figure 6 which shows a series of sequence photographs at varying times of a 0.22-inch-diameter aluminum sphere after penetrating a 1/8-inch-thick aluminum bumper. The impact velocity in this case was 13,400 ft/sec. The two vertical lines visible in the photographs behind the bumper are reference marks and are out of the plane of the projectile.track. Once the standoff was sufficient to essentially eliminate any compound cratering, further increases in the standoff had no effect on the penetration.

Also indicated in figure 5 is the apparent necessity for the bumper standoff to be at least eight times the diameter of the impacting projectiles for a maximum penetration depth to be obtained such as observed in figure 1. At standoff distances below about 8 projectile diameters the penetration appears to always increase with increasing the impact velocity. When the standoff distance was greater than about 8 projectile diameters the maximum penetration was obtained at an impact velocity of 9,000 ft/sec and this

maximum penetration was not influenced by the exact standoff distance. This fact may indicate that relatively short standoff distances will be sufficient to limit meteoroid penetrations of spacecraft. However, there are other factors to consider which may govern the required spacings between bumpers and main structural walls. Two such factors are the possibility of the total pressure pulse generated by the impact of a cluster of bumper and impacting particle fragments being sufficient to bend the main wall and produce a crack or to produce a spall from the back surface of the main wall. To reduce these types of damage considerably greater spacings may be required than those just sufficient to limit the penetration.

The effect of bumper shield thickness.- Figure 7 shows the variations of penetration with impact velocity into six target arrangements that varied only in bumper thickness. The bumper thicknesses in curves (a) through (f) of figure 6 were 0.16, 0.25, 0.50, 1.0, 2.0, and 4.0 projectile diameters, respectively. In curve (a) the penetration increased throughout most of the velocity range of the data reaching a penetration depth of about three projectile diameters at an impact velocity of 11,000 ft/ sec. The very thin bumper shields used in these targets were unable, in the velocity range investigated, to fragment the projectiles sufficiently to reduce the penetration depths.

In the (b) curve of figure 7 the penetration increased to an observed maximum of slightly less than three projectile diameters at a velocity of 10,000 ft/sec then decreased with additional increases in velocity until a velocity of about 12,000 ft/sec was reached at which point the penetrations again began to increase with still further velocity increases. The fastest impact velocity on these bumper shields which was in excess of 15,000 ft/sec still failed to fragment the projectiles to the degree necessary to cause the penetration depths to diminish with increasing impact velocities. The dip occurring at impact velocities slightly greater than 10,000 ft/sec results from the start of fragmentation. In curves (c) and (d) the bumper thickness was sufficient to permit extreme fragmentation of the projectiles within the velocity range investigated. Both of these curves follow the same general trends observed in figure 5 with an apparent maximum penetration of about 2-1/4 projectile diameters being obtained at an impact velocity of about 8,000 ft/sec.

In curve (e) the largest portion of the total penetration observed from each impact was in the bumper shield due to its thickness. At velocities above 10,000 ft/sec the penetrations observed appear to be remaining very nearly constant with further velocity increases at a maximum value of 2.75 projectile diameters.

In curve (f) the impact velocities investigated were not sufficient to permit the complete penetration of the bumper shields. The penetration depth in the bumper shields increased with increasing impact velocities reaching a value of about 3.75 projectile diameters at the maximum impact velocity obtained.

By observing the maximum penetrations obtained with the varying bumper shield thicknesses shown in figure 7, an indication of the most effective bumper thickness can be obtained. Figure 8, is a plot of the maximum penetrations observed in figure 7 as a function of the thickness of the bumper shields. The maximum penetrations taken from curves (c), (d), and (e) of figure 7 are felt to be probably the maximum penetration that can be obtained with the respective target arrangements used; in curves (a), (b), and (f) the maximum penetrations were not established. It was established, however, that these maximum values will be at least equal to or greater than the maximum penetrations obtained during these tests.

The bumper shield thickness investigated which provided the greatest protection appears to be about 1/2 the projectile diameter.

As mentioned before, all of the back main walls of the target arrangements used in this investigation were thick enough to be considered quasi-infinite. Designers of spacecraft are interested in the minimum finite thickness of material required to defeat impacting projectiles or meteoroids.

Calculations were made to determine the total finite thickness of material required in a bumper and main back wall structure to just defeat the projectiles used in this investigation. The results of reference 1 were used in making these calculations which indicated that finite plates 1.5 times the penetration depths observed in quasi-infinite targets are required to just defeat the projectiles. The results of these calculations are shown in figure 9 which is a plot of the total thickness of material required to defeat the impacting projectiles on the ordinate and the bumper thickness plotted on the abscissa. It can be seen that the minimum thickness of material required to defeat the projectiles is about three projectile diameters with the bumper shield thickness equal to the projectile diameter. This means the main wall thickness must be twice the projectile diameter in order for the total of the bumper and the wall thickness to be equal to the value of three projectile diameters. It also should be noted in figure 9 that varying the bumper thickness by plus or minus a factor of 2 produces results which are almost equally effective.

The curves shown in figures 8 and 9 are for the particular materials used in this investigation. It is, however, felt that the trends observed will also be observed for the cases of meteoroid impacts against any materials used in bumper and main walls of spacecraft. It is therefore felt that they can be extremely useful as a guide in designing space structures for penetration protection.

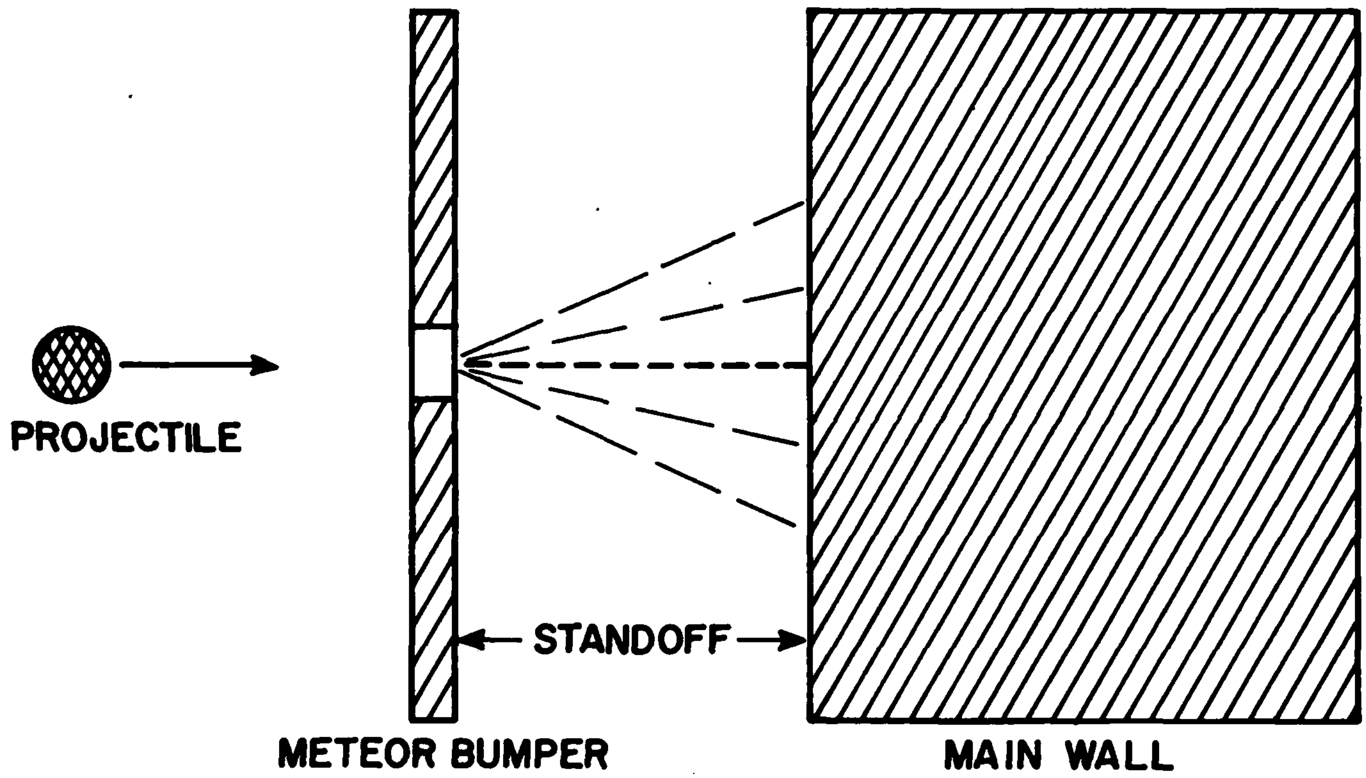
Concluding remarks.- Results of this "Meteor Bumper" investigation have indicated that impact damage from high velocity particles can be greatly reduced by using a properly selected bumper shield. With such properly selected shields the penetration damage on bumper protected wall

combinations was observed to be limited to a maximum value which occurred at relatively low impact velocities. The bumpers were observed to be effective only if they are spaced greater than 8 projectile diameters in front of the back wall. Stand-off distances greater than this may be necessary to limit bending or spalling of the back wall, however, they will not reduce the maximum penetration that can be achieved in the bumper protected wall.

The optimum design for the conditions of this investigation to defeat the projectiles used was found to be a bumper shield equal to the diameter of the impacting projectiles, a stand-off of 8 projectile diameters or greater, and a back main wall equal to twice the diameter of the impacting projectiles and also equal to twice the thickness of the bumper shield.

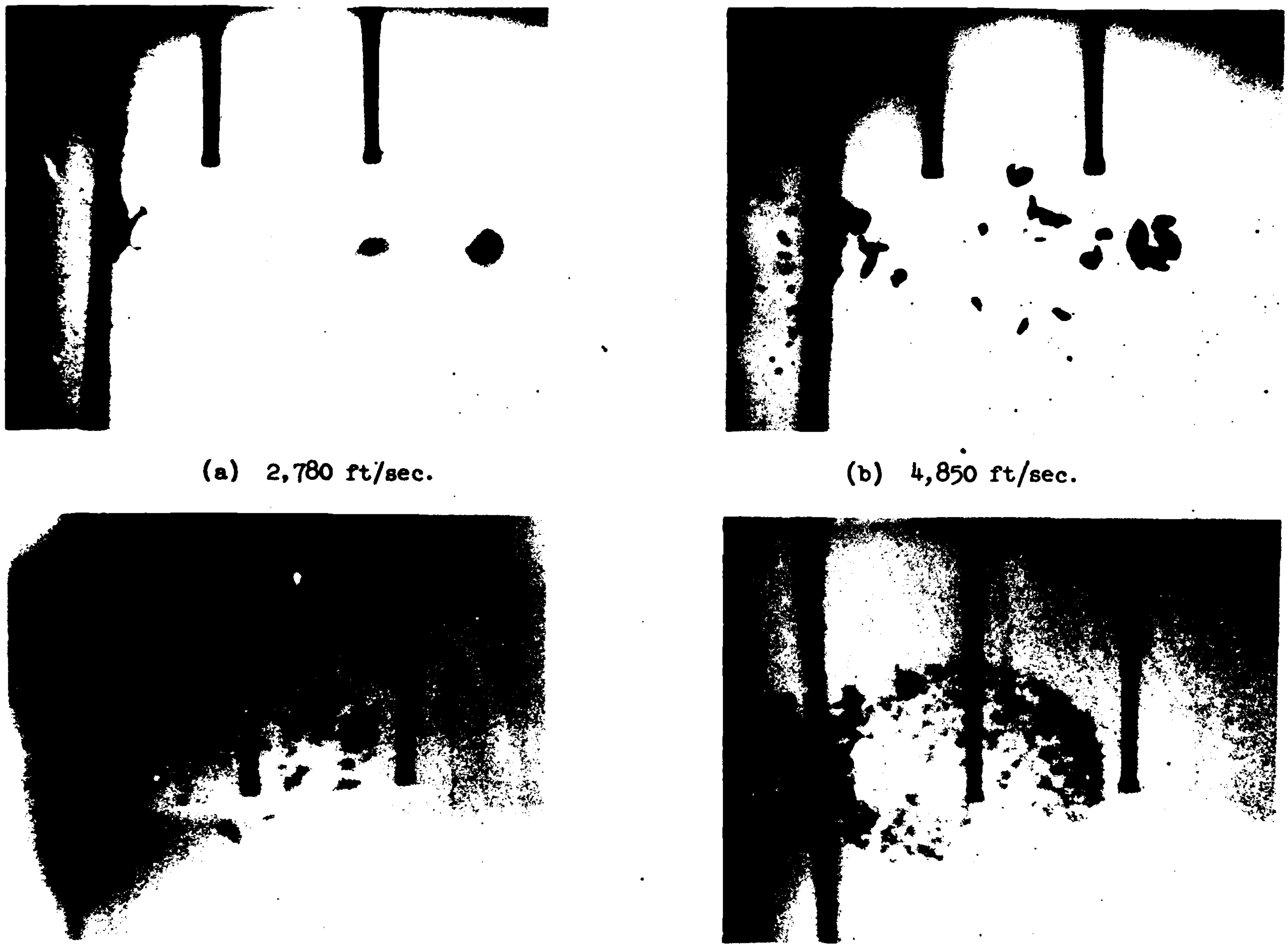
Reference

1. Kinard, William H., Lambert, C. H., Jr., Schryer, David R., and Casey, Francis W., Jr.: Effect of Target Thickness on Cratering and Penetration of Projectiles Impacting at Velocities to 13,000 Feet per Second. NASA MEMO. 10-18-58L, 1958



NASA

Figure 1.- Sketch of meteor bumper configuration.

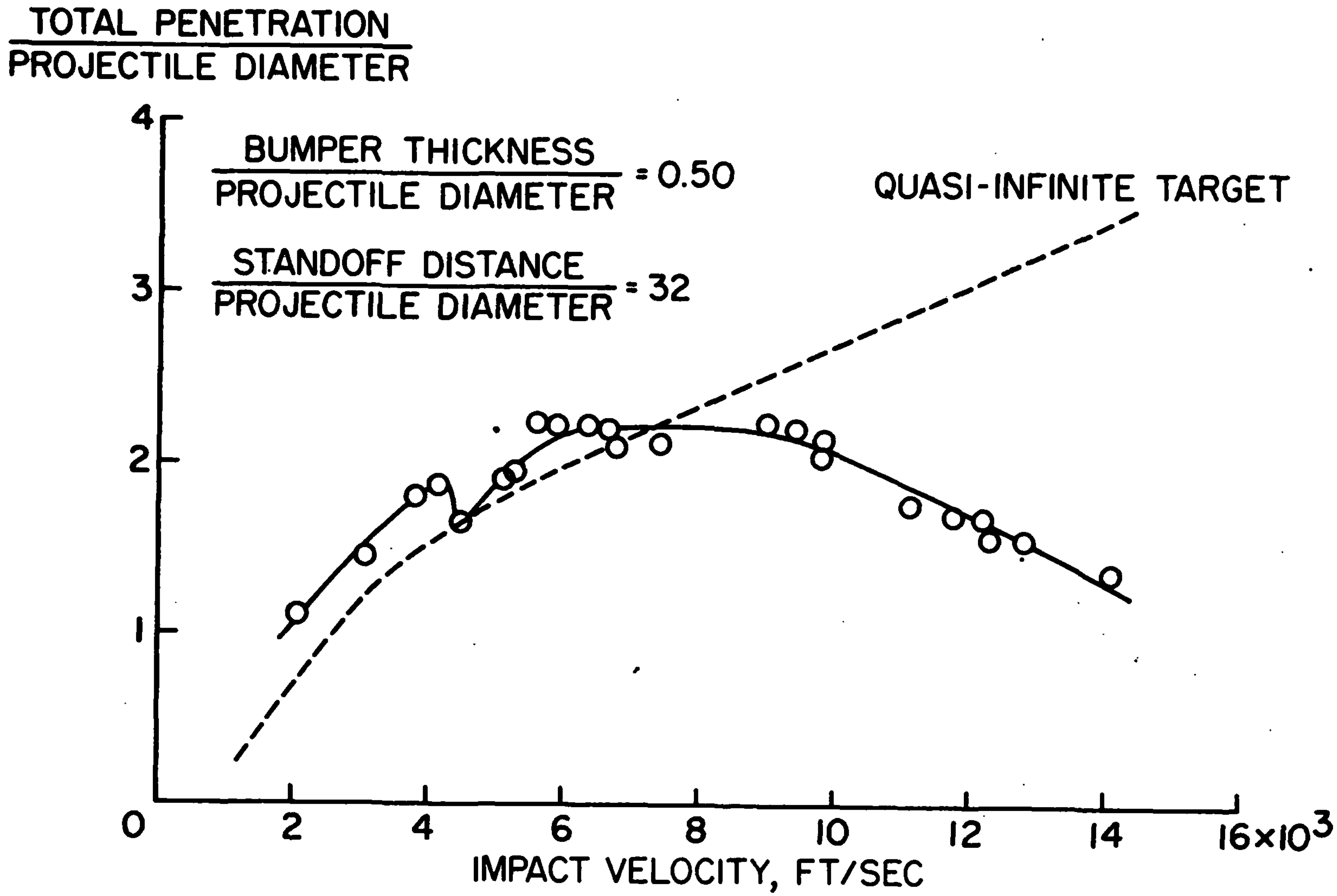


(a) 2,780 ft/sec. (b) 4,850 ft/sec.

(c) 7,250 ft/sec. (d) 13,400 ft/sec

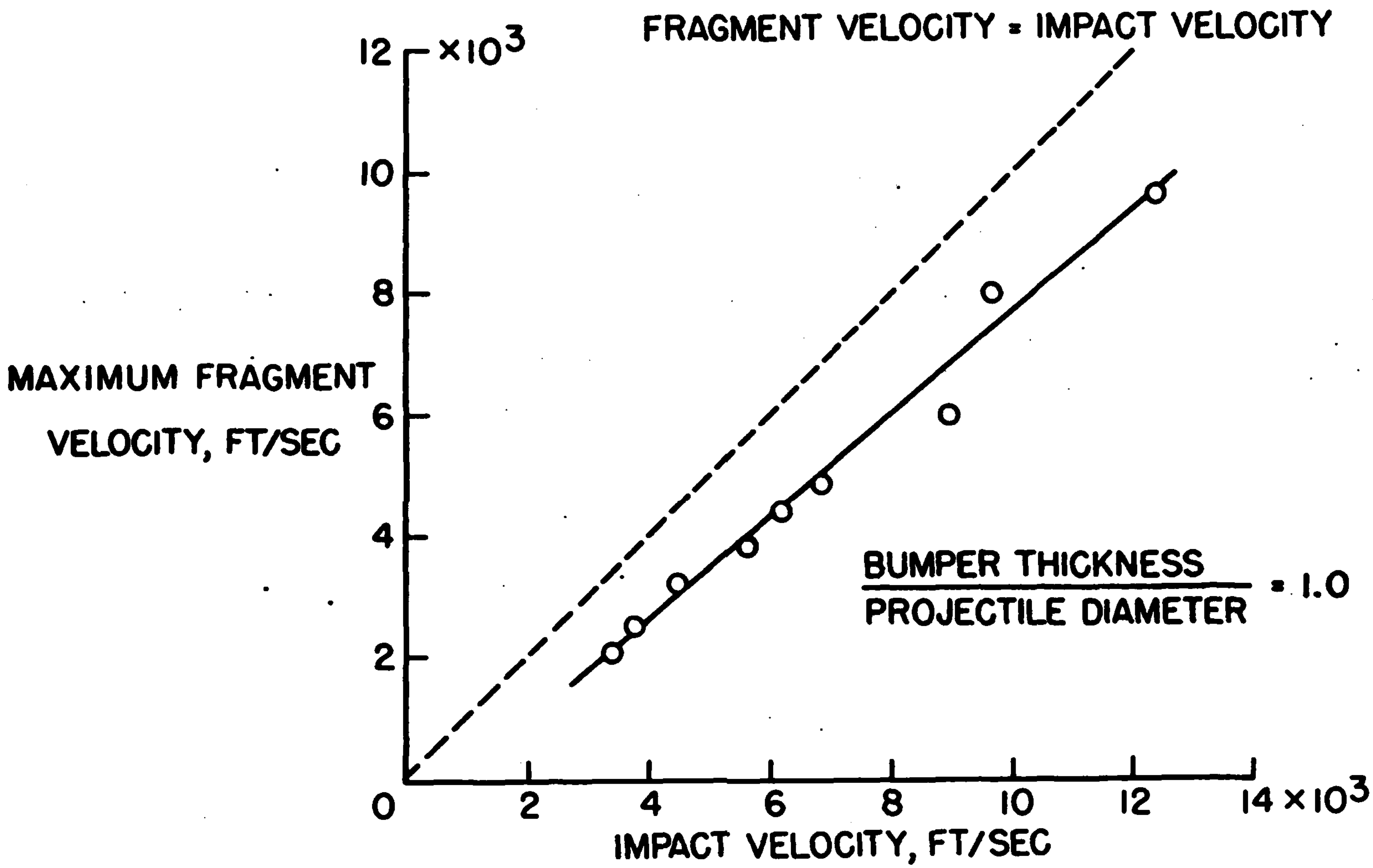
NASA
L-61-5071

Figure 2.- Projectile fragmentation by bumpers at varying impact velocities.



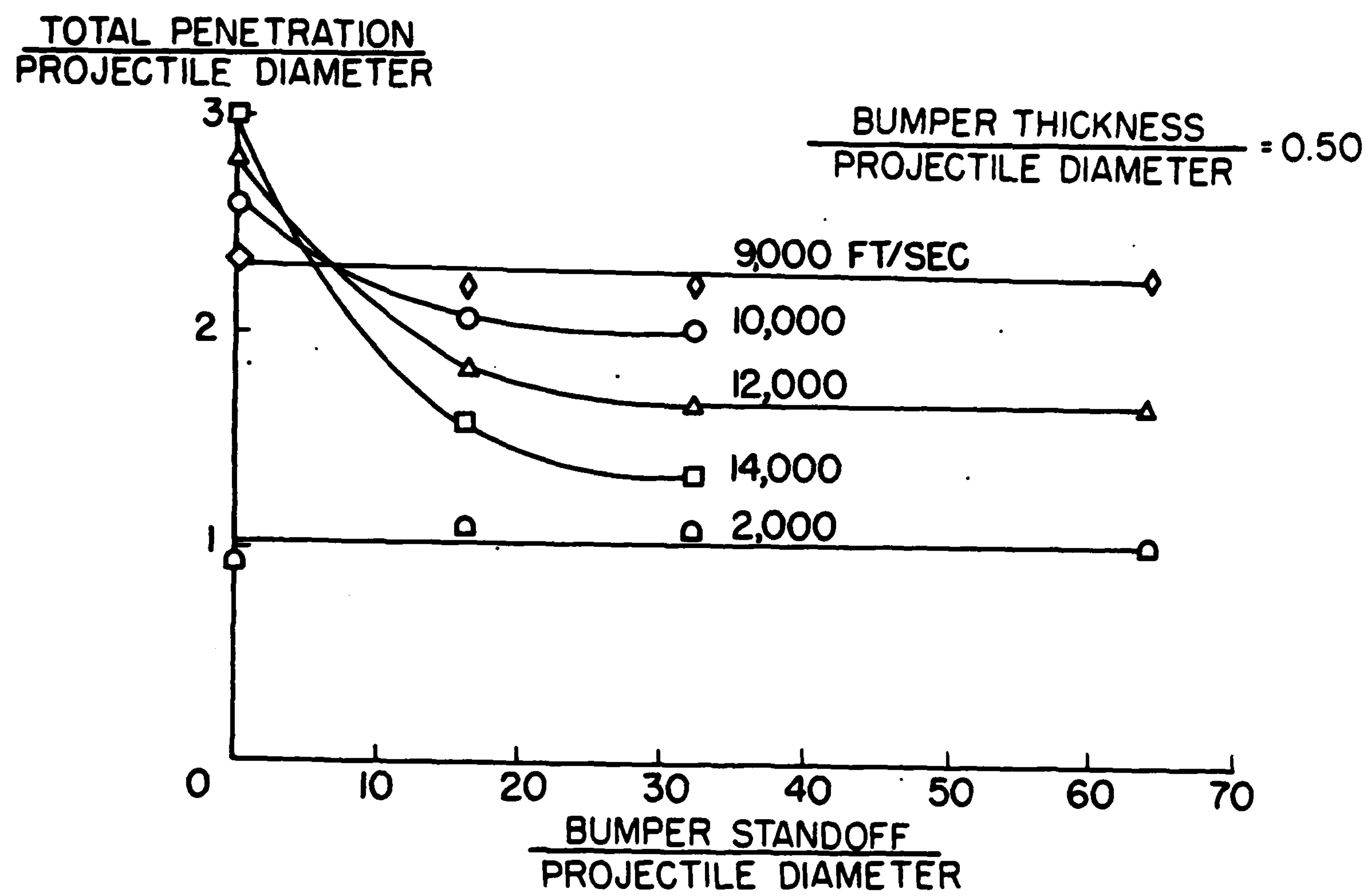
NASA

Figure 3.- Variation of total penetration with impact velocity in a bumper protected target.



NASA

Figure 4.- Maximum fragment velocities observed at varying projectile impact velocities.



NASA

Figure 5.- Effect of bumper standoff distance on penetration at varying impact velocities.

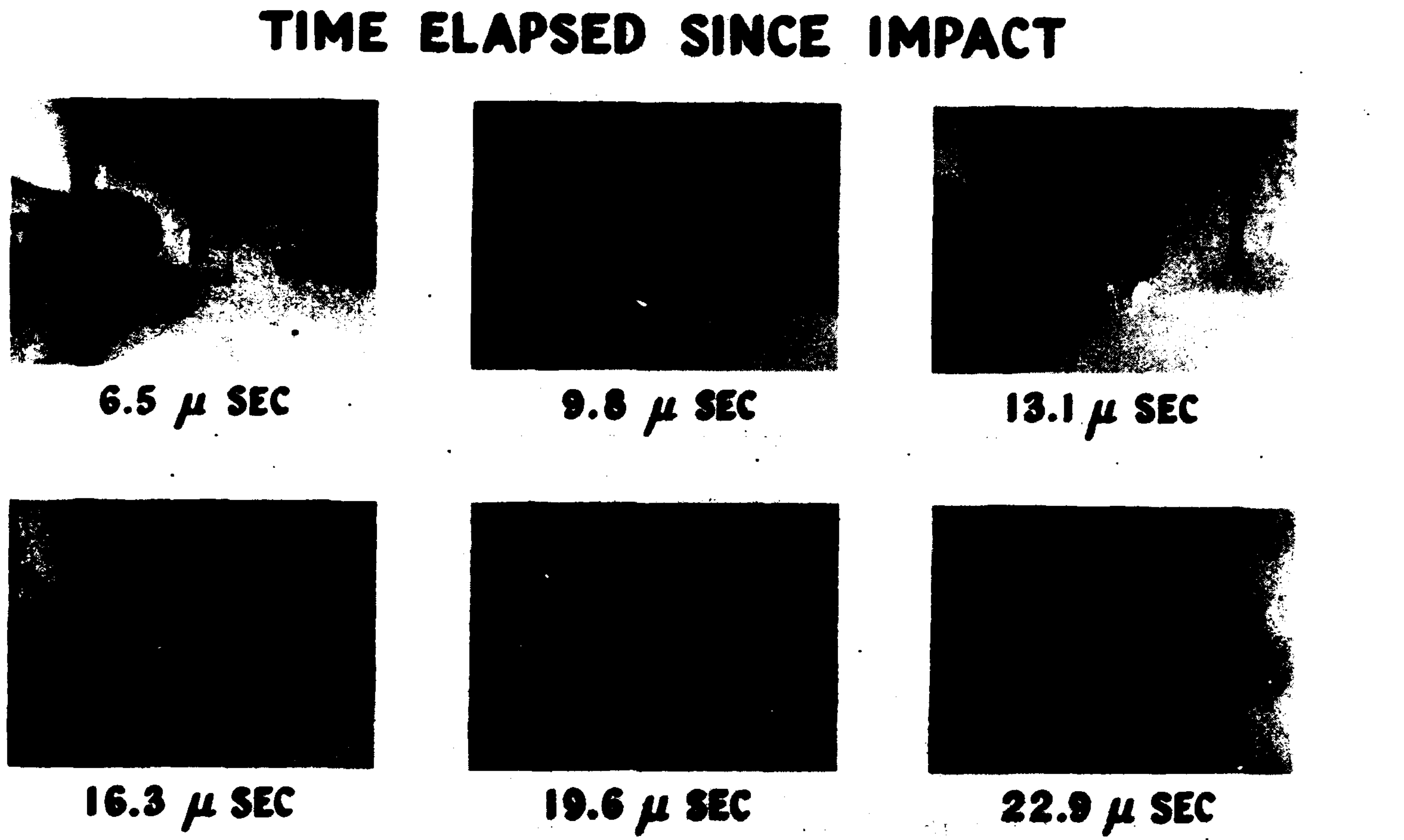
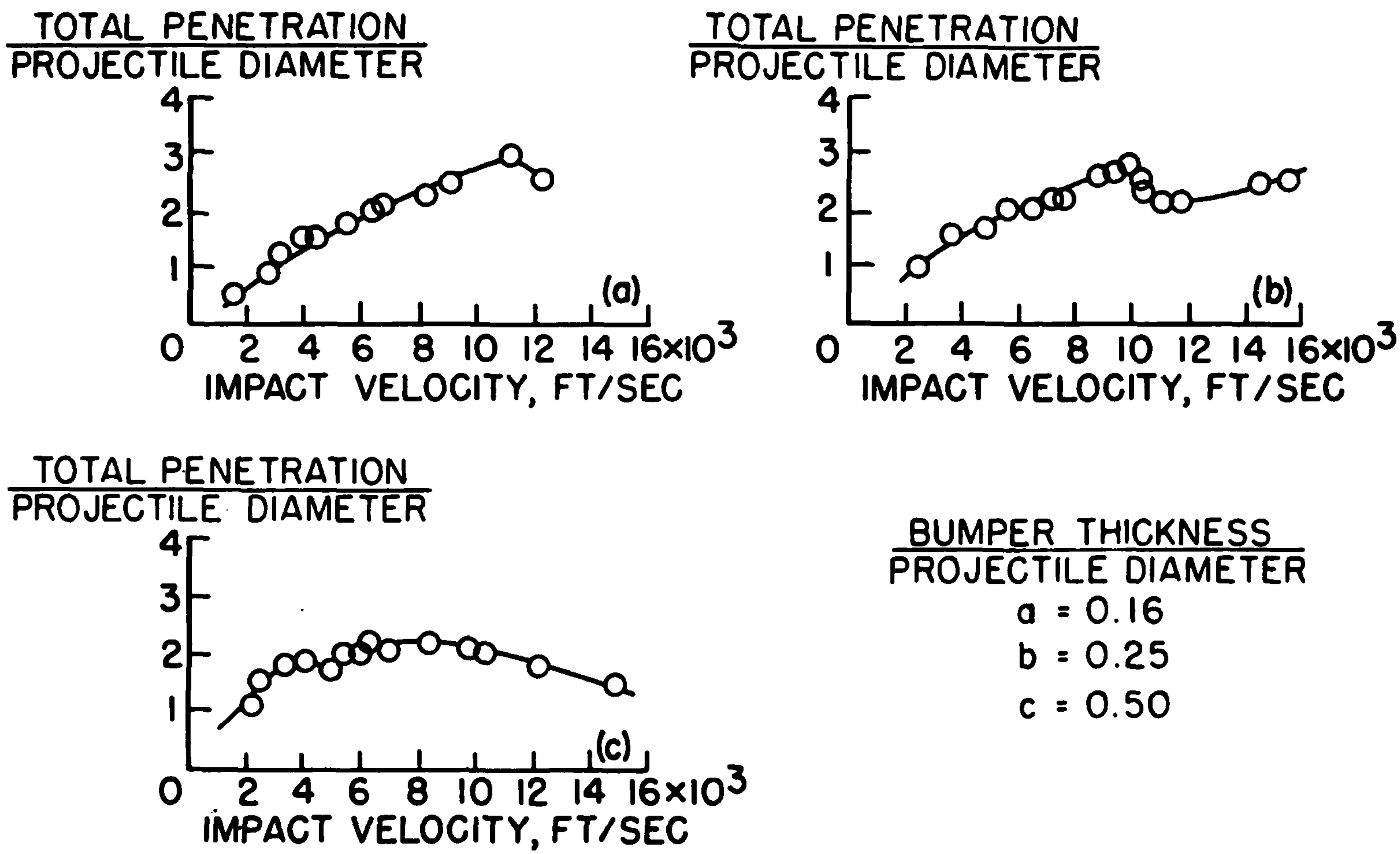
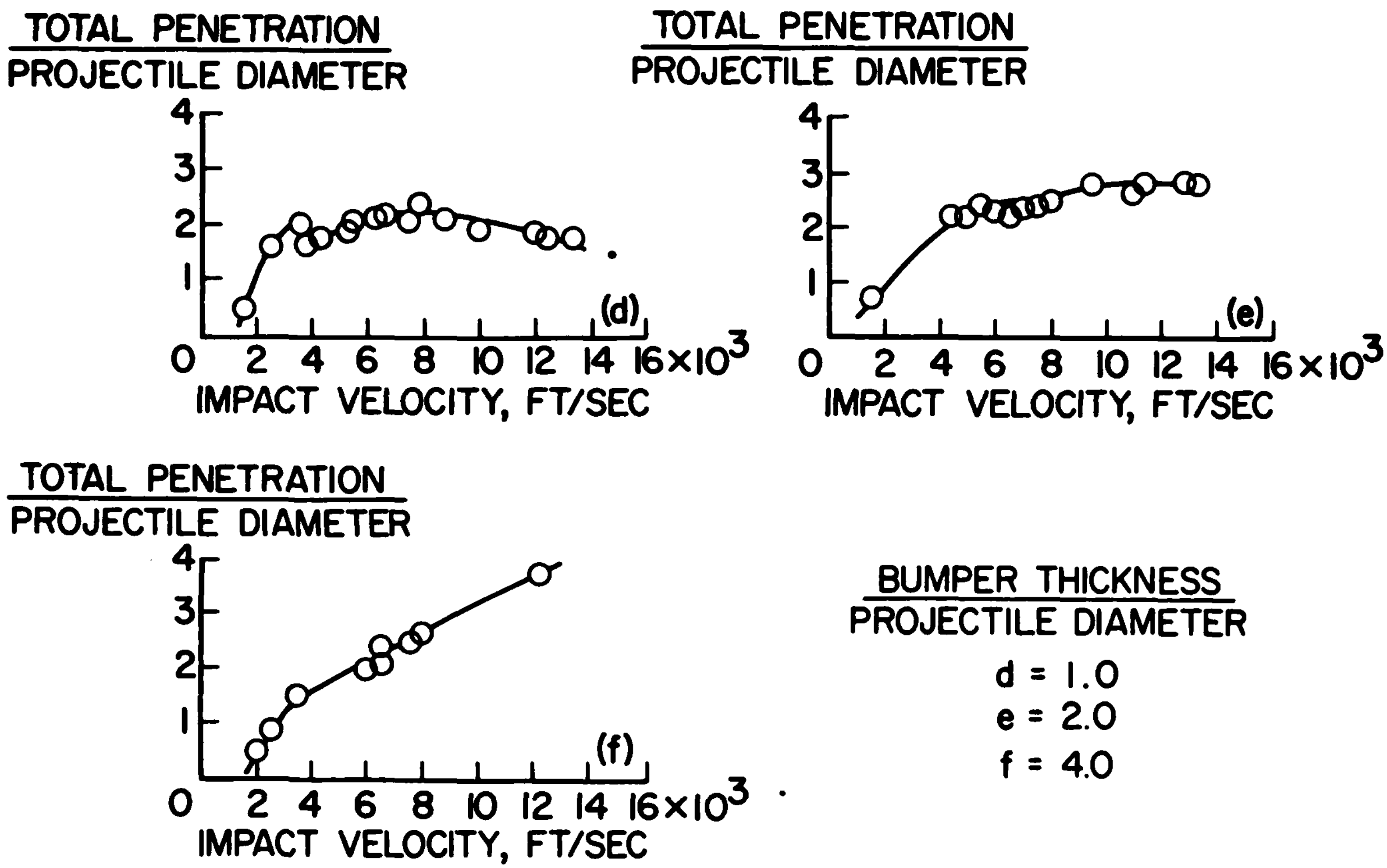


Figure 6.- Effect of bumper standoff distance on penetration at varying impact velocities.



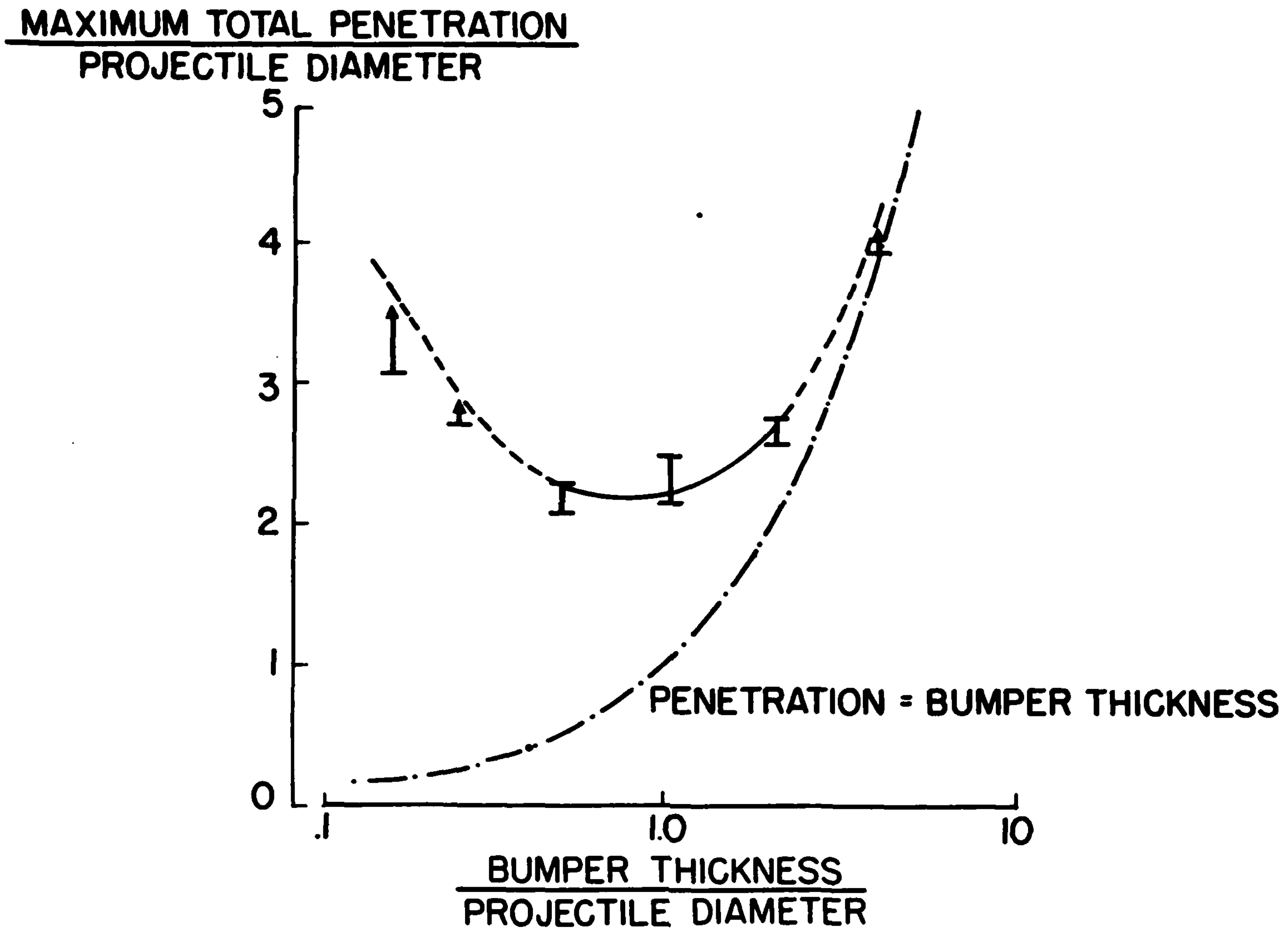
NASA

Figure 7.- Effect of bumper thickness on the variation of total penetration with impact velocity.



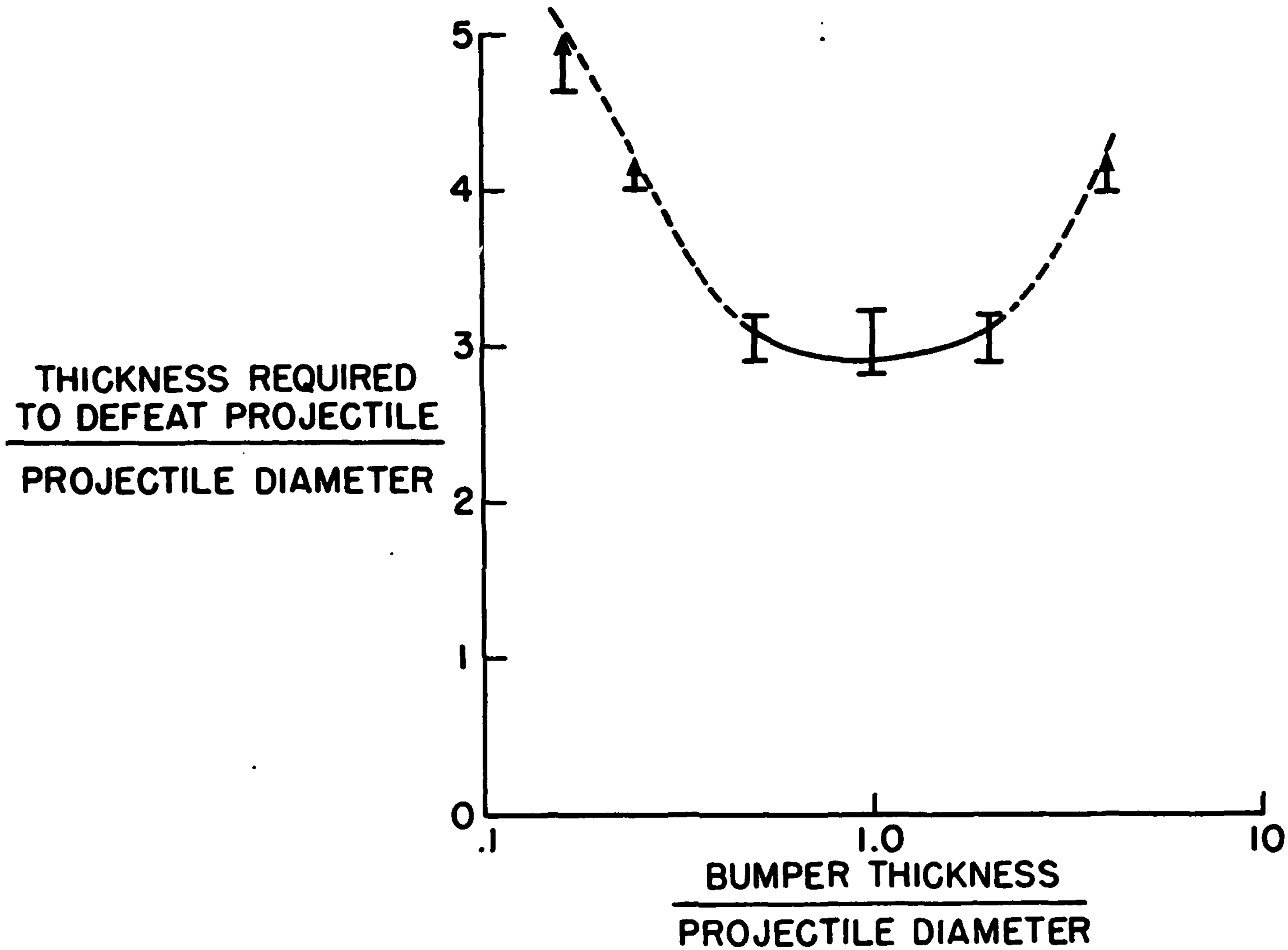
NASA

Figure 7.- Concluded.



NASA

Figure 8.- Effect of bumper thickness on maximum penetration.



NASA

Figure 9.- Effect of bumper thickness on the minimum material required to defeat projectile.